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Report No. 8926-092

Material - Adhesives - Structural - FM-47
(Bloomingdale Rubber Co.)

Tensile and Peel Strength Relations

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Abstract

Tension (Mil-Std-401A) specimens and T-peel specimens, which applied force normal to bond lines at a constant linear rate of failure in the bond between two bonded aluminum alloy strips, were prepared with fiberglass cloth reinforced (supported) and non-reinforced FM-47 (Bloomingdale Rubber Co.) structural adhesives. Generally, all adhesives used were pre-cured at 220°F for one hour prior to bonding at 320°F for one hour under a pressure of 100 psi. Various combinations of testing temperature, adhesive weights and bond line thicknesses were tested to arrive at an empirical expression which related the metal peel strength of FM-47 bonds to the mechanical properties of the resin and facings. This relation is given as follows:

$$\frac{FD}{W} = K\, T_s\, m^{5/3} \left(\frac{T_s\, t}{E}\right)^{1/3}$$

where: F = applied force, pounds; d = moment of applied force, inches; W = width of specimen, inches; K = a constant; T_s = strength of resin in pure tension, psi; m = thickness of facing, inches; t = thickness of bond line, inches; and E = modulus of elasticity of resin, psi.

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A DIVISION OF GENERAL DYNAMICS CORPORATION

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STRUCTURAL ADHESIVES
FM 47 PEEL STRENGTH

MODEL: REA 7038

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INTRODUCTION:

FM 47 adhesive (Bloomingdale Rubber Co.) is a high strength adhesive with low creep characteristics. It does not require refrigerated storage. Compared with other adhesives, its cost is low. It is somewhat brittle at 75°F. (as compared with rubber based adhesives) and has lower measured peel strengths. Aircraft parts are not ordinarily subjected to peeling loads. But design engineers are concerned with the possible implications of low peel strengths.

OBJECT:

The purpose of this investigation is to answer the following questions:

1. What are the peel characteristics of FM 47?

2. What is the significance of these characteristics?

3. How are these related to the mechanical properties of the resin and the facings?

4. What techniques with FM 47 may give more favorable characteristics?

DEFINITIONS:

To peel is to separate bonded facings by progressive failure starting at one end.

T-peel strength is the force normal to the bond line required to maintain a constant linear rate of failure in the bond between two bonded strips. The standard test used in the Engineering Test Laboratories, CSD, is a rate of failure of five inches per minute between two .020" x 1.0" x 9.0" 2024-T3 alclad strips.

The terms brittle and flexible as used in this report are arbitrary. A brittle adhesive is one which fails by fracture in the temperature range of a test.

A flexible adhesive is one which fails by creep rupture in the temperature range of a test.

CONCLUSIONS:

The metal to metal T-peel strength of FM 47 bonds is related to the mechanical properties of the resin and facings by the empirical equation:

$$\frac{F\,d}{W} = K\,T_s\,m^{5/6}\left(\frac{T_s\,t}{E}\right)^{1/3}$$

F = applied force (pounds)

d = moment of applied force (inches)

W = width of specimen (inches)

K = a constant

Ts= strength of resin in pure tension (psi)

m = thickness of facing (inches)

t = thickness of glue line (inches)

E = modulus of elasticity of resin (psi)

(See appendix for derivation)

When 9×10^3 psi is taken as Ts and 6×10^5 psi as E, K is about 3 for 2024-T3 alclad.

FM 47 bonds fail by fracture in the temperature range from -90°F. to + 100°F. and by creep rupture in the range + 110°F. to 190°F. (Tables II and III).

The force required to maintain a constant rate of peeling is increased by increasing the rate in the flexible temperature range, but it is only slightly affected by rate in the brittle temperature range. (Tables II, III, V).

The strands of fiberglas mesh in the adhesive act as expansion joints in the resin. Their primary effect in peel tests is to increase the flexibility of the failed facing and its attached resin throughout the brittle temperature range. These expansion joints may slightly improve load distribution, but the evidence of tests is still inconclusive on this point.

Forced drying of both FM 47 primed surfaces and FM 47 film in a vented (not circulating) oven at 220°F. for one hour is necessary. Failure to force dry the film as well as the primed surfaces has resulted in poor bonds.

Peel strength tests show no inadequacies of FM 47 as a structural adhesive.

RECOMMENDATIONS:

Standard peel strength tests are recommended for quality control.

The data reported on standard peel tests are not sufficient for engineering evaluation and are not recommended as a reliable source for design information.

TEST SPECIMENS:

T-peel test specimens were one inch wide. Specimens with numbers preceded by the prefix S were bonded as sixteen by sixteen inch panels and cut into strips using a table saw. Specimens with numbers without a prefix were bonded as individual strips.

Drum peel test specimens were three inches wide and bonded as individual specimens.

Tension test specimens were one by one by one inch aluminum alloy cubes bonded together in pairs.

All FM 47 adhesive liquid and film used in this test had been stored in the laboratory for at least one year without refrigeration and without special wrapping or care. One lot of FM 47 liquid adhesive had been stored in the laboratory for at least five years.

All FM 47 primed surfaces and film on test specimens reported were force dried for one hour at 220° F as recommended by the Bloomingdale Rubber Co.

Unless otherwise noted in notes on tables, the bonding time was 60 ±5 min., the bonding temperature was 320°F ±10°F, and the bonding pressure was 100 ±10 psi. Parts were cooled to 150°F under pressure.

AF 32 tape on EC 1660 primed surfaces was used where comparisons with rubber based adhesives were desired.

TEST PROCEDURE:

References:
Tensile test (in tension) - MIL STD 401A
T-peel tests - CSD Spec. 22-01310
Drum Peel Test - MIL STD 401A

Standard test procedures were used as far as possible. These were modified only to the extent necessary to obtain the information desired.

Appropriate sketches to illustrate test procedures used are included on each sheet of tabulated data.

The moment of the applied force in T-peel tests was measured with a straight

TEST PROCEDURE: (Continued)

edge and rule. The machine was stopped for measurements of the moment when testing within the brittle range of the adhesive. It was necessary to make measurements during the application of the load when testing within the flexible range of the adhesive. The probable error in measurements of the moment of the applied force is estimated to be .05 inches.

Force measurements reported are from automatic recorders.

There was some difficulty during the tension tests of FM 47 due to shearing of steel pins and deformation of aluminum parts under load. Some of the deviations in values may have been due to uneven application of loads, i. e. deformed parts not aligning properly. (Table I)

RESULTS: Results are tabulated in Tables I through V.

DISCUSSION OF RESULTS:

T-peel test data first collected were found to be incomplete and useless as soon as attempts were made at analysis. Other T-peel tests were therefor undertaken in which the moment of the applied force was measured.

In drum peel tests it was found that the skin at the point of failure does not conform to the surface of the drum. The flange on this apparatus interferes with measurements. The data on this test (shown in Table V) is useful only for possible indications of creep characteristics at 75°F.

FM 47 supported film is manufactured in three weights .03, .05, and .07 pounds per square foot. The threads of the fiberglas mesh are spaced about .1 inches apart. The unsupported film (type 0) is intended for use in filling spaces where there is a mismatch of parts.

The fiberglas strands do not supply enough bulk to appreciably change the mechanical properties of the resin. They are found, however, to act as expansion joints in the resin. Examination of failed peel specimens shows the facing material to be bent back sharply along each transverse strand. These bends follow each transverse strand exactly.

The FM 47 resin remaining on the failed facings of peel specimens add to their stiffness. The fiberglas strands allow the failed part of the facings to bend more readily. This decreases the moment of the applied force, and the force reading increases sharply. When two layers of film are used the strands are brought into more intimate contact with the facings. They are then more effective in reducing failed facing stiffness.

DISCUSSION OF RESULTS: (Continued)

With type O unsupported tape the fractures are irregular and the moment of the applied force changes sharply and abruptly.

The rubber based adhesives are brittle adhesives below their freezing (second order transition) point, about +28°F. The usual force reading with AF 32 at -65°F. has been about eight pounds. To test the above observations, two layers of AF 32 film were bonded between 2024-T3 Alclad facings with a layer of scrim cloth next to each facing. When tested at -65°F. the force reading was 28 pounds. The moment was measured as .35 inches. The product of the force and its moment is 9.8 inch pounds.

When the peeling load is applied, the inner surface of the metal facing is stretched. The expansion joints due to the glass threads may relieve some of the stresses which result from this strain in the facing. It is possible that such joints allow a better distribution of loads. Neither of these possibilities can be confirmed by data available at the present time.

In the flexible range of an adhesive very small changes in the strength of a bond result in large changes in the moment of the applied force. This gives a large magnification of the changes in the quality of a bond in terms of force. The standard T-peel tests are therefor excellent quality control tests. Simultaneous measurements of force and its moment would be required for design information. Such simultaneous measurements of acceptable accuracy would require the use of photography. The information may be obtained more easily by direct measurements of mechanical properties.

NOTE: The original data upon which this report is based is in Structures and Materials Laboratory Notebook No. 987.

TABLE I
Tensile Strength in Tension

Identification	Film	Time (min)	Cure Temp. °F	Pressure (PSI)	Test Data Load (Lbs)	Area Sq.In.	Load (PSI)	Avg
	FM 47							
1	.05#(2)	60	320	100	6640	.904	7370	
2	"	"	"	"	9200	.904	10020	
3	"	"	"	"	8080	.873	9250	
4	"	"	"	"	8660	.890	9750	9098
	FM 47							
5	Type 0	60	320	100	8040	.864	9320	
6	"	"	"	"	6400	.890	7180	
7	"	"	"	"	8850	.904	9800	
8	"	"	"	"	6600	.836	7900	8550
	FM 47							
9	.05#	60	300	100	6750	.950	7120	
10	"	"	"	"	6660	.950	7020	
11	"	"	"	"	6500	.950	6850	
12	"	"	"	"	6480	.950	6830	6960
13	AF 32	60	325	100	-	-	-	
14	"	"	"	"	2100	.950	2210	
15	"	"	"	"	2050	.950	2160	
16	"	"	"	"	2100	.950	2210	2193

Specimens 1,2, 3, and 4. Two layers of .05 Lb/cu.ft. FM 47 film used. One layer of film used on all others.

Specimens were prepared by bonding two 1" x 1" x 1" aluminum alloy cubes together-- MIL STD 401 A 15 June 56, par 5.2.3.1 and Fig V page 19. See sketch right, below

Test temperature: Room Temperature

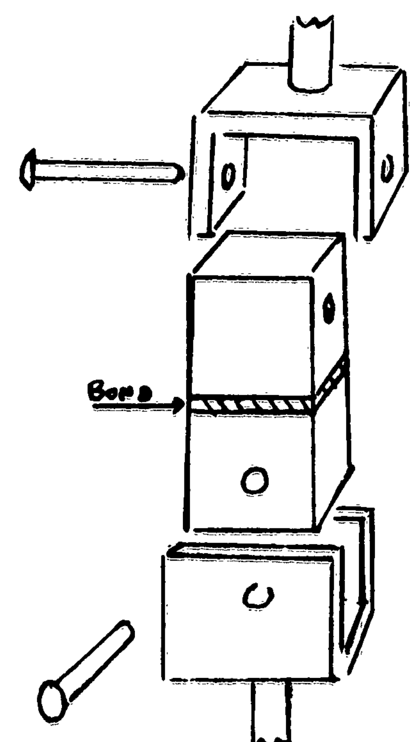
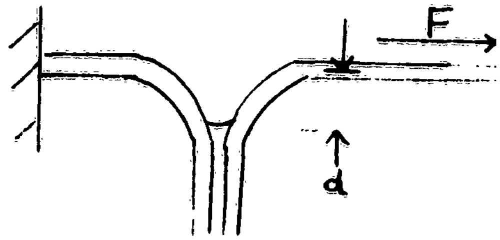


TABLE II
T-Peel +190°F to -80°F
Single layer of film

Identification	Facings (inches)	Glue line Thickness (inches)	Test Temp °F	F (Lbs)	d (inches)	F x d	Failure
S11	.020	.008	-80	11	.8	8.8	Fracture
S25	"	"	-60	14	.7	9.8	"
				16	.6	9.6	"
S17	"	"	-40	16	.75	12.0	"
S12	"	"	-20	12	.8	9.6	"
S16	"	"	0	20	.5	10.0	"
S24	"	"	+10	18	.5	9.0	"
S3	"	"	+20	22	.5	11.0	"
S4	"	"	+32	20	.45	9.0	"
S14	"	"	+75	22	.48	10.56	"
S22	"	"	+120	32	.3	9.6	Creep rupture
S20	"	"	+130	50	.15	7.5	"
S7	"	"	+140	40	.23	9.2	"
S2	"	"	+160	44	.25	11.0	"
S9	"	"	+180	41	.27	11.0	"
After machine stopped, 1 min.				23	.37	8.5	"
S15	.020	.008	+190	38	.2	7.6	"
After machine stopped, 1 min				34	.33	11.3	"
X	.064	.011	+185	50	1.8	90.0	"

All specimens one inch wide.
S numbers:
Facings -.020" 2024 T3 Alclad
Adhesive - 1 layer .05#/sq Ft FM 47 film
Bonding - 60 min x 320°F x 100 psi
X
Facings - .064" 2024 T3 Alclad
Adhesive - 1 layer Type 0 Fm 47 film
Bonding - 60 min x 320°F x 100 psi

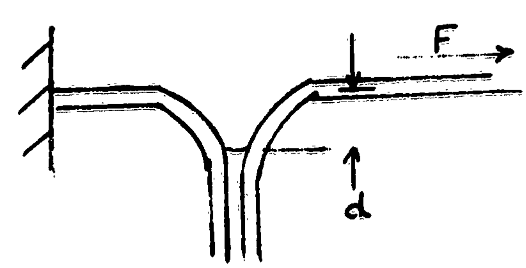


Rate of peel: 5 inches/minute
Cooling: Immersion in methyl and isopropyl alcohol cooled to test temperature with solid carbon dioxide.
Heating: Immersion in water heated to test temperature.
Soak time: 10 to 15 minutes.
Tested immersed.

TABLE III
T-Peel - 90°F to + 190°F
Double Layer Adhesive Film

Identification	Facings (inches)	Glue line Thickness (inches)	T°F (test)	Force (F) Pounds	d (inches)	F x d	Failure
S31	.020	.015	-90	19	.5	9.5	Fracture
S34	"	"	-70	29	.5	14.5	"
S45	"	"	-50	25	.45	11.2	"
S44	"	"	-30	29	.3	8.7	"
				16	.7	11.2	"
S32	"	"	-10	27	.4	10.8	"
S47	"	"	+ 8	25	.4	10.0	"
S41	"	"	+20	26	.5	13.0	"
S28	"	"	+32	25	.4	10.0	"
S36	"	"	+40	30	.4	12.0	"
S50	"	"	+50	34	.38	12.9	"
S38	"	"	+60	35	.35	12.2	"
S51	"	"	+77	35	.35	12.2	"
S37	"	"	+100	40	.28	11.2	"
				38	.32	12.16	"
S49	"	"	+110	44	.28	12.3	Mod. Creep Rupture *
After machine stopped 1 min.				33	.28	10.6	" " "
S52	.020	.015	+120	45	.25	11.2	Creep Rupture
S43	"	"	+130	60	.15	9.0	"
S29	"	"	+140	55	.15	8.2	"
S30	"	"	+160	54	.25	13.5	"
After machine stopped 1 min				30	.35	10.5	"
S39	.020	.015	+180	45	.25	11.2	"
After machine stopped 1 min				26	.32	8.2	"
S42	.020	.015	+190	47	.2	9.4	"
After machine stopped 1 min				22	.35	7.7	"

All specimens 1 inch wide
Facings - .020" 2024 T3 Alclad
Adhesive - 2 layers .05#/sq ft FM 47 film
Bonding - 60 min x 320°F x 100 psi
Rate of peel - 5 inches/minute
Cooling - Immersion in methyl and isopropyl alcohol cooled to test temperature with solid carbon dioxide
Heating - Immersion in water heated to test temperature
Soak time - 10 to 15 minutes
Tested immersed



*Moderate amount of creep

TABLE IV
Room Temperature T-Peel

Identification	Glue Line Thickness (inches)	Film FM 47	Layers	Facing Thickness (inches)	Force (F) (pounds)	Moment (d) (inches)	F x d
1	.005	.03#	1	.010	15	.2	3.0
2	.008	"	2	.010	20	.15	3.0
3	.011	.05#	1	.010	24	.13	3.12
4	.016	"	2	.010	27	.12	3.24
5	.004	.03#	1	.020	14	.6	8.4
6	.008	"	2	"	43	.25	10.75
7	.012	.07#	1	"	29	.35	10.15
8	.023	.07#	2	"	46	.25	11.5
S1	.010	.05#	1	"	21	.48	10.8
S6	.010	"	1	"	24	.48	11.52
S14	.010	"	1	"	22	.48	10.56
S19	.010	"	1	"	23	.47	10.81
S5	.008	"	1	"	24	.45	10.8
S8	.008	"	1	"	26	.45	11.7
S10	.008	"	1	"	25	.47	11.7
S18	.008	"	1	"	24	.47	11.28
S21	.008	"	1	"	26	.45	11.7
S23	.008	"	1	"	25	.45	11.25
S26	.008	"	1	"	25	.45	11.25
S27	.016	"	2	"	33	.33	10.89
S33	.016	"	2	"	38	.3	11.4
S40	.016	"	2	"	30	.4	12.0
S46	.016	"	2	"	28	.42	11.76
S51	.015	"	2	"	35	.35	12.2
S35	.015	"	2	"	33	.39	12.87
S46	.015	"	2	"	32	.4	12.8
9	.010	"	1	.040	14	2.2	30.8
10	.018	"	2	"	15	2.1	31.5
11	.023	"	3	"	22	1.6	35.2
12	.030	"	4	"	31	1.25	38.75

Bonding
60 min x 320°F x 100 psi
Rate of peel: 5 inches/min
Test Temp.: 70°F to 80°F

Facing material
2024 T3 Alclad

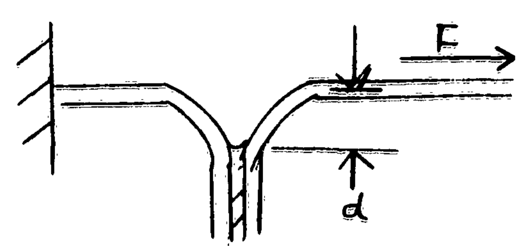


TABLE V
Drum Peel Tests

Identification	Glue line Thickness (inches)	Film	Layers	Arc (inches)	Gap (inches)	Machine Head Travel (in/min)	Av. Load (pounds)	Corr.* Load (pounds)	Comp. Torque** (inch-Lbs/in.)
		FM 47							
A	.003	.03#	1	Not Measured	Not Measured	.5	211.5	204	34
B	.003	"	1			.5	188.7	181.2	30.2
C	.007	"	2			.5	288.6	281.1	46.8
D	.007	"	2			.5	277	269.5	44.9
				1.0	.05 - .8	.04	255.6	248.1	41.3
				1.0	.05	.02	260.7	253.2	42.2
				1.0	.05 -.8	.02 - .1	252.4	244.9	40.8
E	.008	.05#	1	Not Measured	Not Measured	.5	247	239.5	39.9
F	.008	"	1			.5	254.4	246.9	41.1
G	.015	"	2			.5	236	228.5	38.1
H	.015	"	2			.5	200	192.5	32.1
I	.009	.07#	1			.5	227.5	220	37
J	.011	"	1			.5	210	202.5	33.7
K	.022	"	2			.5	149	141.5	23.6
L	.012	Type 0	1			.5	135	127.5	21.3
M	.006	AF 32	1			.5	855	847.5	141.2
N	.006	"	1	1.5	.1 -.15	.04	656	647.5	107.9
				1.5	.1 -.15	.02	624	613.5	102.2

Top skin: .020" x 3" x 12" 2024T3 Alclad
Bottom skin: .125" x 3" x 8" Al Aly

Bonding:
Specimens A to D and I to M 60 min x 320°F x 100 psi
Specimens E to H 90 min x 320°F x 100 psi
Test Temperature: Room Temperature

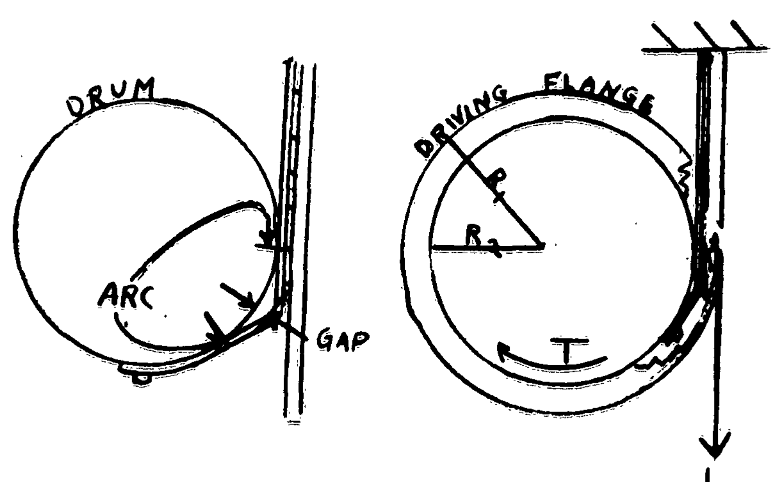
Blank: (.020" x 3" x 12" 2024 T3 Alclad) 7.5 pounds load

R_1: 2.5 inches

R_2: 2.0 inches

Specimens M and N tested for comparison. AF 32 is a rubber based adhesive.

*corrected
** computed



REFERENCES

1. Handbook for Adhesives, Bloomingdale Rubber Co., Chester, Pa.

   Processes for Bonding - Section I
   Properties of Metal to Metal Bonds - Section 2.2

2. ANC-23 Sandwich Construction for Aircraft.

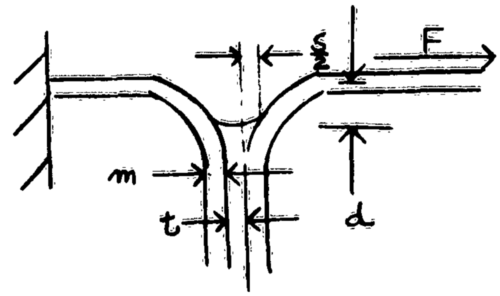
   Part II, 1955, Air Research and Development Command.

   Summary of test results in evaluation of FM 47 (Glenn L. Martin Co. Engineering Report 4265-7) - Col. 11, Table 2-3, page 44.

3. Handbook of Chemistry and Physics, Chemical Rubber Publishing Co., Cleveland, Ohio.

   Variation of Temperature with Altitude, page 3127.

APPENDIX



Derivation of the T-Peel Equation

The applied force and its moment are set equal to resistance to the peeling torque.

$$\frac{F\ d}{W} = K_1\ T_s\ \frac{A}{s} \tag{1}$$

F = applied force
d = moment of the force
W = width of the specimen

K_1 = a constant
T_s = tensile strength of the adhesive in tension
A = area of bond under load

The area, A, will be proportional to the amount of deformation the adhesive will undergo before failure and to the resistance of the facing in the area under load to bending.

Empirically the effect of the thickness of the facing, m, is found to be in the order of $m^{5/3}$. If the adhesive deforms an amount, s, before failing, and the system behaves as a loaded cantilever beam, then

$$A = K_2\ m^{5/3}\left(\frac{s}{2}\right)^{\frac{1}{3}} \qquad \text{Where } K_2 \text{ is a constant.} \tag{2}$$

Assuming that the deformation of the adhesive follows Hooke's law,

$$s = K_3\left(\frac{T_s}{M}\ t\right) \tag{3}$$

Where M = the modulus of elasticity of the adhesive
t = the glue line thickness
K_3 = a constant

Substituting the equivalent expressions for the area in equation 1, and collecting constant terms into the single constant, K

$$\frac{F\ d}{W} = K\ T_s\ m^{5/3}\left(\frac{T_s}{M}\ t\right)^{1/3}. \tag{4}$$